CHAPTER 4

MECHANICAL

4-1. General. Design and operation of mechanical systems in arctic and subarctic regions are basically similar to those Systems used in the northern regions of the continental United States; however, extended periods of extremely low temperatures and high wind conditions of the arctic can cause failures in systems that function normally in other areas. Therefore, mechanical system design for arctic regions must utilize arctic-type technical changes and economic considerations. Systems should be as simple as possible to avoid operator confusion. Operation and maintenance considerations are important since expert technical assistance may not be available at isolated arctic sites. Components should be standardized whenever possible to reduce the inventory of repair materials necessary. Material in this chapter should be used to supplement applicable technical manuals.

4-2. Heating.

a. General A satisfactory, reliable, and easy to maintain heating system is extremely important for personnel comfort. Remote locations, severe climatic conditions, and short daylight hours which all tend to confine personnel to the site are primary reasons for maintaining a good physical environment. Cold floors and downdrafts from windows should be minimized by using adequate floor insulation and locating heating units below windows. While constant circulating heat systems will usually provide more uniform room temperatures, it is important that all available information be evaluated before selecting a system. To provide further design guides, various types of heating systems are discussed in detail below. Noted are the advantages or disadvantages of each when used in the arctic environment. Unless otherwise stated herein, heating designs shall be in accordance with TM 5-810-1.

(1) *Hot air heating.* Hot air heating is one of the simplest and most widely used systems in arctic areas. Major advantages are that it is less expensive to construct, is easily understood, and requires less maintenance. Systems with extensive ductwork, however, are expensive to ship, difficult to install, and can be difficult to balance. When reliable electrical power is available, forced-air heaters with gun type oil or gas fired burners should be utilized as operation is more efficient and less costly. Forced-air heaters must be separated from the rest of the building by a 1-hour fire rated partition. Low-cost ventilating can be provided by bringing dampered outside air into the building through the furnace cold air return. Where large quantities of fresh air are required, however, a split system should be used. Forced-air heating systems can utilize duct mounted humidifiers to increase humidity, and filters to control dust. Blowers in hot air furnaces distribute heat effectively and should be operated continuously for best results. Hot air supply outlets should be located near the floor to induce increased circulation in office and living spaces and in buildings with many open spaces and high ceilings. Fans to move the hot air from the ceiling toward the floor are extremely desirable. Air systems are not generally damaged by freezing if power is lost, and little preventive maintenance is necessary.

(2) *Steam and hot water heating.* Central steam and hot water heating systems are the most widely used in arctic regions because of the simplicity of heat distribution. Heat storage in steam and water systems can prevent freezing during short power failures; however, a rapid means of emergency drainage is essential. These systems require immediate attention if a problem develops, therefore alarm systems should be installed. The use of thermostat draindown valves developed for solar systems should be investigated. In addition to heating, the steam and hot water systems can provide a practical and economical heat source for various water treatment processes. Steam and hot water can also be used to melt snow for domestic water. Anti-freeze keeps hot water systems from freezeup.

(a) Steam heating Systems. Steam is used extensively in heat distribution systems and in primary building heating systems. Steam heating can be used for shops, hangars, and garage-type buildings where system noise and wide ranging temperatures are not objectionable. Conversely, steam is undesirable in offices and living spaces because of noise problems and lack of precise control. Steam can be piped long distances where unavoidable pressure losses would be excessive if using a normal hot water system. Adequate condensate and steam line slopes must be provided to avoid freezing damage during outages. Drip legs and receivers also require protection from freezing. Provide automatic condensate drainage with steam traps such as the thermostatic bellows-type. Good water treatment is required to reduce corrosion in the return lines. Maintain control of pH between 6.7 and 7.7 to avoid excessive corrosion. Pure condensate (pH 7), however, can cause rapid pipe deterioration.

(b) Hot water systems. The same types of hot water systems are used in arctic areas as in temperate climates, however, positive control and system reliability must be provided. As mentioned above, the primary advantages of hot water over steam are uniform temperature control, relatively quiet operation, and much less maintenance because there is no condensate return system. To prevent freezing, antifreeze solutions should be utilized. Hot water or antifreeze systems are very effective in panel heating, which provides even heat distribution over large radiating surfaces. Radiant floor temperatures should not exceed 70°F. However, when outside temperatures are below -65°F, radiant floor panels may not give off sufficient radiation to heat the building unless the floor temperature is raised above the comfort limits recommended by American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Handbook of Fundamentals. Additional insulation or dual systems may be required to maintain proper floor temperatures in this case. Where insulation is used under the floor heating system, designers need to consider its effect on the thaw bulb. Consideration also needs to be given to: the heat's effect on the floor slabs; effect of shrinking on the designers selection of contraction joint spacing; designing heating loops to contraction joint spacing to minimize crossing of control joints. High density polybutylene tubing is recommended rather than copper or steel because of its greater flexibility and lower corrosiveness. If leaks develop, radiant floor systems are hard to repair because such leaks are difficult to locate. Hot water or antifreeze systems are most widely used in building perimeter heating systems (fin-tube radiators), which are very effective in providing even heat distribution. The hot water or antifreeze system can be set up with temperature reset controls which reset the hot water or antifreeze operating temperature based on the outside air temperature, thus saving energy.

(3) *Electric heating systems.* Electric heating systems can be utilized in areas where electric power is economically available. The advantages of electrical systems-ease of installation, distribution, control, small space requirements, and low initial cost-make electric heating appealing. The operating costs for electric heating systems are generally higher than for other systems. Where major changes such as increasing the size of wall studs to accommodate the extra insulation are required to make operational costs competitive, the total cost of installing an electrical system may exceed that of other systems. Electric heating may also be limited by the size of the base power plant. Favorably, however, electric heaters can also be used for tempering outside air for ventilation.

(4) *Gas heating Systems.* Both propane and natural gas heating systems can be utilized effectively in arctic climates. When using propane, precautions should be taken to heat and maintain the propane cylinder and regulator at the proper temperature to vaporize the gas. At atmospheric pressure, propane liquefies at a temperature of 44°F, therefore, tanks must be protected from such cold, non-vaporizing temperatures. Where these tanks are enclosed, a ventilation system is necessary to prevent any hazardous gas accumulations. Natural gas can be piped long distances even in arctic climates. Orifices and controls can freeze and become inoperative when gas containing water vapor expands or is subjected to freezing temperatures. In these cases, heaters and water separators must be used. An alcohol can also be entrained into the dried gas to prevent freezing of condensed moisture in the system. The water-alcohol mixture is collected at low drain points in the piping systems, where it is expelled using a blow down connection. Natural gas can also be used effectively for heating outside air for ventilation.

b. Heating problems in cold areas. Problems outlined below may be encountered in mechanical systems because of the arctic environment. The systems must be modified to operate properly.

(1) *Freezing of water and steam systems.* A temperature alarm system should be installed in each remote unoccupied building to alert maintenance personnel when the building's inside temperature approaches freezing.

(a) Heating lines and equipment Running hot water lines in exterior walls is not recommended. If lines must be placed in exterior walls, however, they must be properly protected. When the boiler, furnace, or heat exchanger ceases to function, localized freezing of water in the system can be delayed if constant circulation is utilized. Other problems can occur. Where automatic room temperature control is not provided, personnel may open windows to provide necessary control and lines may freeze when the room is left unattended. For this reason, individual room thermostat controls should be provided. In garages or hangars, unit heaters installed within 20 feet of doors should be interlocked with those doors, so that the fans on the unit heaters shut off when the doors open. When fans are left running, cold outside air is blown over the coil, and it frequently freezes.

(b) Antifreeze system design problem. The most common antifreeze solutions are made up of approximately 50 percent by volume of ethylene glycol and 50 percent by volume of water. Pumps in ethylene

glycol systems must utilize mechanical seals to prevent leakage. Glycol in its pure state is a corrosive liquid, therefore, rust inhibitors must be added to eliminate corrosive effects. Inhibitors break down and deteriorate at high temperatures, forming a sludge and increasing the solution's corrosiveness. Above 240°F the breakdown can occur very rapidly. To reduce this breakdown, it is recommended that glycol systems not be operated above 200°F. Consideration should also be given to substituting other commercially available antifreeze solutions which are effective and do not deteriorate at higher temperatures, such as heat transfer oils or antifreeze solutions designed specifically for heating and snow melting systems. These antifreezes, usually ethylene glycol solutions, contain inhibitors such as mercaptobenzothiazole, disodium, or dipetassiumphosphates. When using commercial brands of anti-freeze, always be sure to check additive compatibility. Velocity in heating coils and heating tanks should be kept high enough to prevent extensive sludge buildup. Small diameter but longer heat exchangers or multipath heat exchangers can be specified for this purpose. If possible, use straight tube heat exchangers, with removable heads on each end to facilitate routing sludge from tubes. The straight tube exchanger is recommended, but not mandatory, in lieu of the more common “U” tube exchanger. If properly sized to provide a 4 to 6-fps fluid velocity in the tubes, "U" tube heat exchangers are acceptable. Sludge deposits can be particularly bad in heat exchangers or air heating coils where three-way valves are used to control output because of reduced flow through the tubes under lighter loads. Gylcol solutions should be checked frequently to maintain a pH of at least 6.4. Due to the peculiar manner in which water affects glycol ionization, the pH can be varied over a fairly wide range (about 6.7 to 7.7) by adding small amounts of water. It is also good practice to replace glycol yearly. When replacing the glycol, the system should be completely flushed to remove sludge deposits.

(2) *Shop and hangar heating.* The frequent opening of large doors and the usual high ceilings in such buildings can create many heating problems. Some items to be considered are:

(a) Fast heat recovery is necessary in hangars and shops to maintain good working conditions. The warm building air can be very rapidly displaced when doors are opened, especially when there are strong winds or cold outside air temperatures. Minimum recovery measured 4 feet above the floor should be from 20°F to 50°F in 120 minutes.

(b) When projection type heaters are used in shops, hangars and other large spaces, units with sufficient throw and a low discharge *air* temperature must be selected. Air throw and projection from the unit should cover the entire floor area. Units selected in this manner will frequently have a larger than required heating capacity so the quantity of water supplied must be specified and controlled. Installation of overhead radiant heaters is economical and they should be considered where gas or cheap electric power is available.

(c) Snow melting systems should be installed under hangar doors and ramps to reduce ice and snow accumulation and keep doors operable. Ramp heating should extend far enough so that vehicle or aircraft wheels make the transition from ice to bare pavement outside the entrance door.

(d) Radiant heating should be considered for hangar and maintenance shop floors in addition to the regular heating system. Heat from floor slabs provides greater comfort for workmen.

(e) Infiltration through windows, louvers, and overhead doors is a major cause of building heat loss in arctic areas. Extreme care in door design and good weather-stripping is required to eliminate excessive losses. In addition, heat loss calculations must include adequate figures to compensate for infiltration. To reduce infiltration, operable windows should be kept to a minimum. Window and door construction methods are covered in chapter 2 in this manual.

(3) *Heating control* Controls for heating and ventilating systems should generally be automatic. Manual control systems should also be provided to preclude complete shutdown if automatic controls fail. Night temperature setback should be considered wherever practical applications exist. Heating coils must have adequate controls to protect them against freezing. Control systems must be kept simple because expert maintenance is often not available.

(4) *Cooling water and recharge well&* Cooling water supply and recharge wells should be considered where outside temperatures are too high to cool electronic equipment during summer months. During winter months discharging waste water in recharging wells, rather than on the ground surface, can effectively reduce ice fog and glaciation. The reduction of ice fog is especially important near airfields. The temperature of well water in subarctic regions is usually not over 39°F.

(5) *Fuel oil design problems.*

(a) Fuel oils used in arctic areas should comply with grade DF-A arctic grade as specified under Federal Specification VV-F-800. Fuel oil meeting this specification has a pour point of -60°F. When used

in areas where such low temperatures prevail, special heating and insulation of fuel lines should be coil is modulated and coils are subjected to outside air, they become vulnerable to freezing. The following should therefore be considered.

(a) Antifreeze solutions. Circulating an antifreeze solution as the heat exchange medium can avoid freezing and the system can operate down to very low temperatures. Some difficulties, however, can be encountered. When coils carrying antifreeze solution pass below freezing air, the steam-antifreeze system heat exchanger can be damaged if the automatic steam control valve or the steam trap serving the heat exchanger fails. Manual bypass valves shall be installed around the control valves and trap assemblies to prevent heat exchanger freeze-ups. It is also possible to freeze up the entire building system from outside air blowing through the ventilating system when the circulating pump fails. This can also happen following a power outage, when the fan automatically resumes operation but the antifreeze solution pump does not. It is good practice to provide a low limit thermostat control in the air discharge from the coil to stop the fan and close the outside air dampers if air temperatures drop to about 35°F.

(b) Steam with face and bypass damper control Coils using steam as the heating medium can be used to heat outside air. However, some precautions must be taken to avoid freezing the coil. A bypass should be incorporated around the heating coil to regulate downstream air temperatures. The steam supply to the coil must *not* be modulated when air temperature to the coil is below 32°F. So-called nonfreeze or steam distributing coils freeze easily under modulated steam supply. In addition, a vacuum breaker should be used on the steam supply to the coil to permit complete coil drainage when steam is shut off. A low-limit thermostat, set to actuate when any single foot of a 20-foot length of bulb is exposed to the set temperature, should be installed on the downstream side of the coil. This thermostat should shut off the fan and close the outside air damper when air leaving the coil is approaching freezing temperature (40°F.) Figure 4-1 shows a control diagram for a heating and ventilating unit with face and bypass control. Note the many controls required for satisfactory operation. Figure 4-2 shows one method in which steam could be used for preheating to prevent frost closure of filters. Again note the complex system. Condensate will leave the coil more readily if vertical nonfreeze coils are used. Steam traps with adequate capacity for the pressure differentials encountered under operation must be used. Traps should be installed not less than 12 inches, and preferably 18 inches, below the bottom of the coils to provide sufficient static head for condensate drainage. Condensate discharge from traps serving coils handling cold air is drained by gravity. The condensate piping from trap to condensate receiver should be properly sized and sloped to reduce back pressure and permit drainage. Much simpler operation can be obtained by using antifreeze instead of steam.

(c) Recirculating air. An effective ventilation system can be provided by reheating return air and mixing it with outside air. This system should be considered if less outside air is needed during winter than summer, and wherever coil freezing is to be avoided. A system that mixes return air with outside air before it goes to the heating coil could also be used. Freezing can occur, however, when cold air and return air do not mix properly before going through the heating coil. Air stratification can occur even after air passes through a centrifugal circulation fan. To reduce stratification, warm air should be brought in at the bottom, and cold air at the top, of the mixing box. Parallel blade mixing dampers should be set to maximize mixing action.

(d) Heat recovery system. Another effective ventilation system uses an air-to-air heat recovery coil or a run-around coil heat recovery system. These systems should be considered where ventilation requires use of 100 percent outside air and exhaust, for example, in maintenance shops or fuel storage areas. These systems extract heat from the exhaust air stream and transfer it to the cold incoming outside air stream. This transfer preheats the incoming outside air before it goes through the fan and heating coil assembly. These types of systems must be evaluated on a life cycle cost basis.

(2) *Outside air openings.* Ventilation requires outside air openings for both intake and exhaust. Improperly designed openings cause many problems in arctic areas, as high winds, blowing snow, and rain come through these openings. Hoods, when used, should be protected from falling ice or constructed to withstand damage from it.

(a) Exhaust openings. In low wind areas, exhaust openings of normal design will be adequate. The openings can be designed with stormproof louvers. If hoods are used, they should extend a minimum of 1 foot below the opening, and be sized to allow air passage without excessive flow loss. Even with fans operating, high winds can prevent air exit. Winds blowing against the building horizontally can move upward and into the hood. This can cause the exhaust fan to rotate backwards when not in operation, and the screens can clog with frost or snow, preventing the system from functioning as intended. During design,

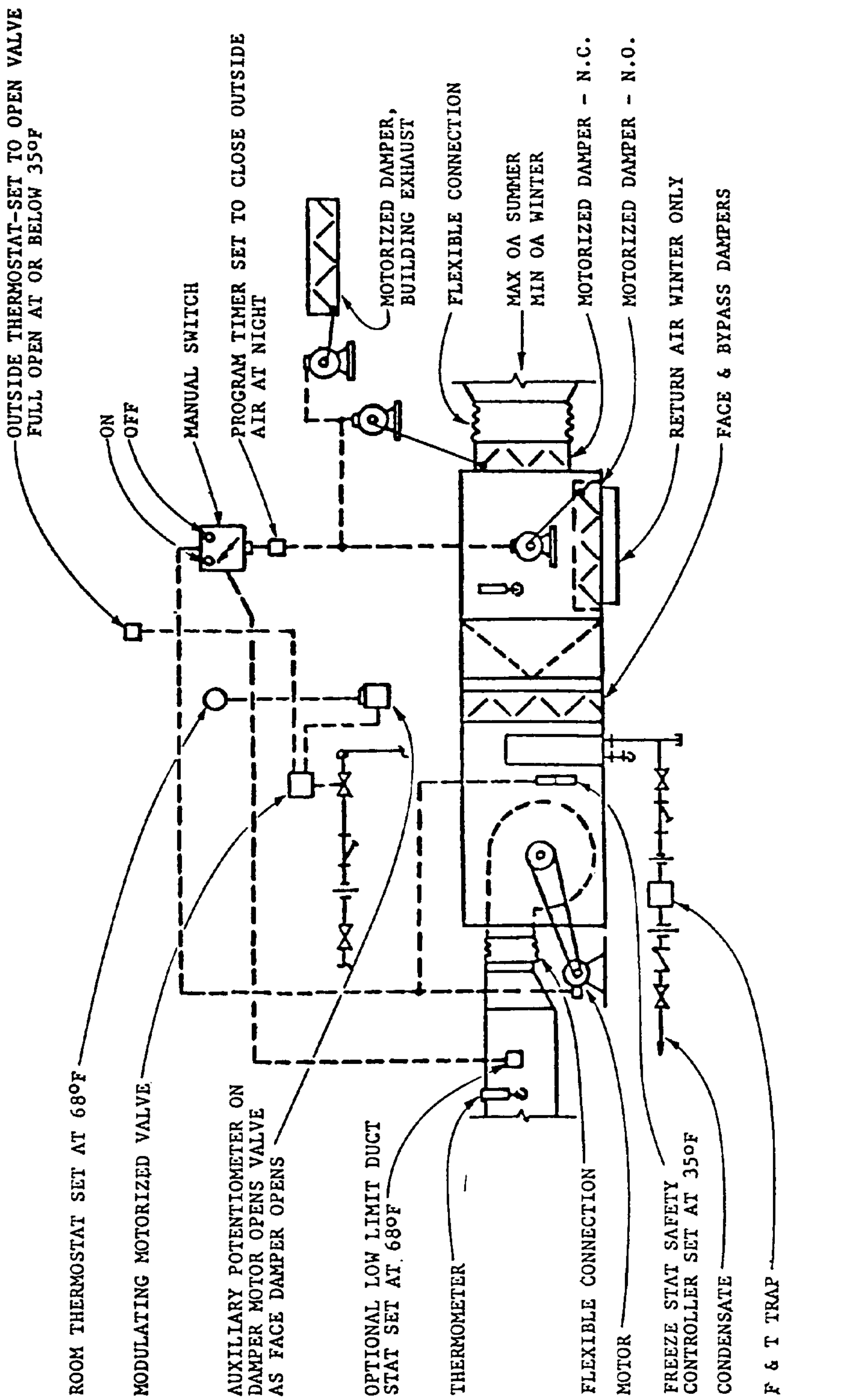


Figure 4-1. Heating and ventilation unit with face and bypass temperature control

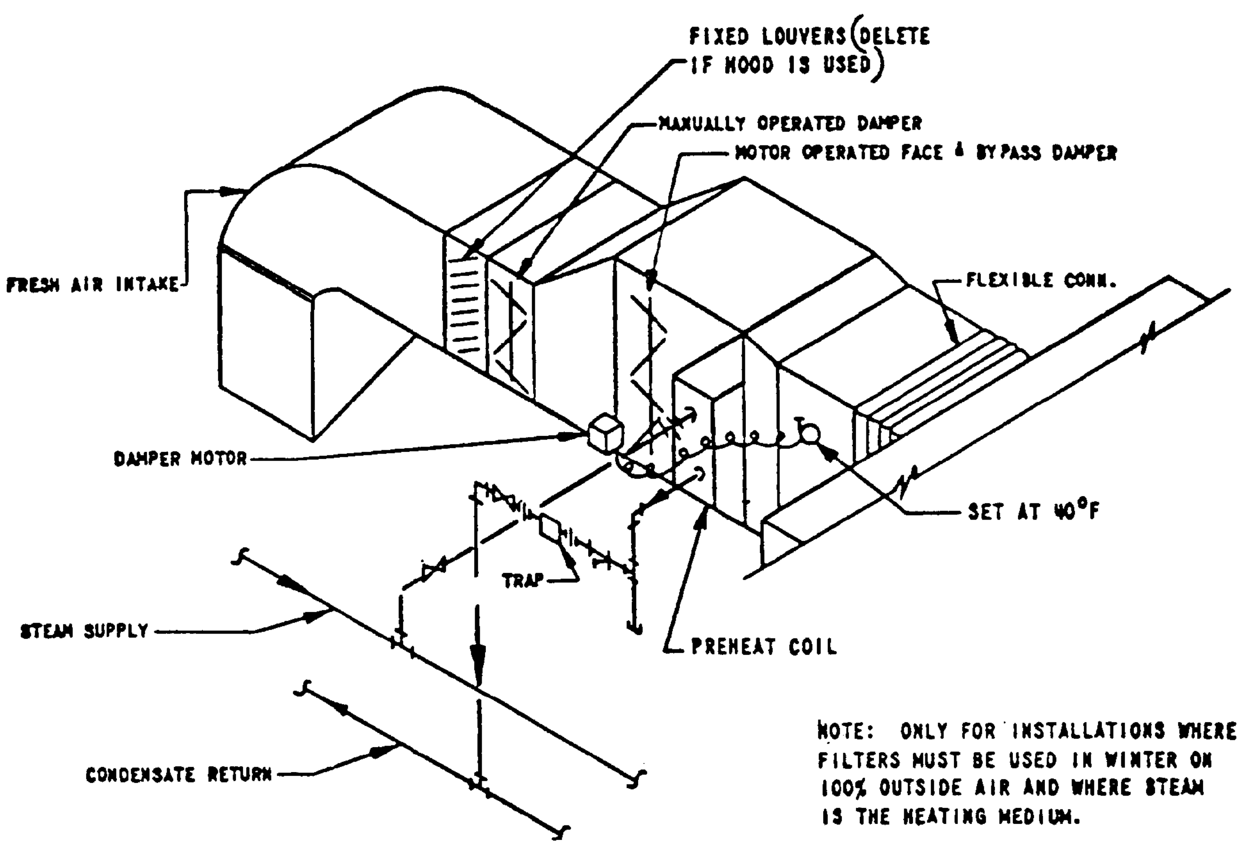


Figure 4-2. Steam preheat coil installation with damper control.

various locations, orientations, and structural features should be considered to minimize these problems. If possible, the exhaust should be located on the downwind side of the building. Exhaust openings can be installed through the roof or, where buildings are elevated on piles above grade, through the floor. Underfloor and wall exhausts should be directed horizontally to keep heated air from contacting pilings or the ground, and degrading the building foundation. Figure 4-3 illustrates what can happen when moist air condenses on the cold metal surfaces and accumulates into a frozen ice mass. Buildings should be slightly pressurized to reduce or eliminate draft through exhaust and other openings.

(b) Intake openings. Where no high winds occur, intakes can be installed directly to the outside with a stormproof louver. Hoods with a series of baffles should be used where there are high winds. The baffles are placed to cause the air path to change, which drops most of the snow, rain, and other foreign particles out of the air stream before it enters the intake duct. Refer to paragraph 2-9 in this manual for additional information and Figures 2-4 and 2-5 on hood design.

(c) Bird screens. To reduce frost closure, install bird screens only (no insect screens) on intake and exhaust openings. In temperatures below approximately 200 F, frost accumulation may close the insect screen openings very rapidly. At -30°F, a 1/2-inch-square mesh bird screen has frozen closed in 6 hours. To reduce such closure, install a 1-inch-square mesh screen which can be removed during summer operations. Removable insect screens can be utilized during warm weather.

(3) *Frosting of filters in ventilation systems.* Icing and frost closure occur when saturated freezing air, usually below -20°F, is brought in through the filter. The same problem can occur when fresh air intakes are too close to the exhaust openings and plumbing vents. Since fresh air intakes, including filter banks, are generally under negative pressure, care should be taken to seal openings and penetrations that permit more humid air to enter the intake duct or filter bank. Several methods of correction are possible. A preheat coil can be installed ahead of the filter to heat the air to 30°F, but that coil can plug with dirt, lint, and other material during normal summer operation. Best results can be obtained by removing the air filters completely

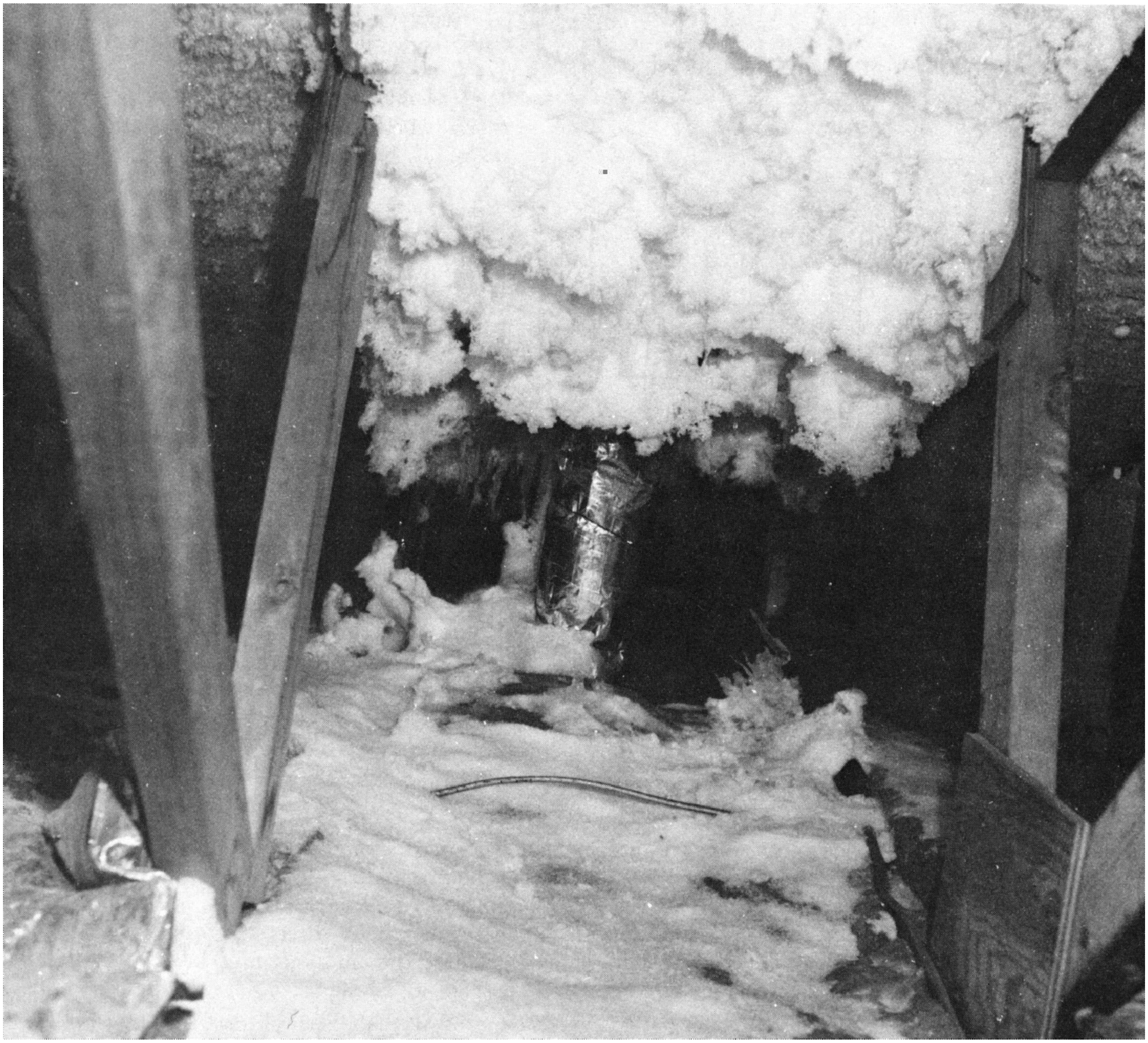


Figure 4-3. Ductwork installed in a cold attic.

during the winter months. Icing and thawing have caused throwaway-type filters to get wet, collapse, and jam the face and bypass dampers. Filter icing has completely choked off an opening in 8 to 10 hours of operation.

(4) *Insulation of ducts and pipes handling cold air.* Pipes and ducts subjected to cold air must be provided with insulation and sealed at the vapor retarder penetration. The ventilating unit should also be insulated up to the heating coil, or to a point where a suitable mixed air temperature is achieved. Insulation should be sufficiently thick to eliminate condensation on the room surface at the duct.

(5) *Special ventilation requirements.*

(a) Barracks ventilation. Living quarters are normally provided with fresh air and ideally the relative humidity should be between 30 and 40 percent. In cold weather, the outside air tends to be very dry and cold. The use of outside air for ventilation results in the loss of heat and humidity, both of which must be replaced to maintain healthy and comfortable living spaces. In very cold weather humidifiers may be required to maintain humidity at acceptable levels. On the other hand, troops hanging large quantities of wet clothes tend to provide temporary and localized areas of very high humidity which can cause condensation problems.

(b) *Shower room ventilation.* Exhaust fans should be installed to remove the moisture from shower or bath areas. Exhaust fans should not be placed within individual shower stalls as this causes cold drafts: the best location is just outside the shower room door. In gang showers, ventilation openings can be in the shower room, but should be near the exit.

(6) *Dining hall/kitchen exhaust systems.* Exhaust fans should not be installed on the roof or the exterior of the building, or immediately above the grease filters where the ambient temperatures may be too extreme for the electric motors. Also, grease which passes the filters is deposited within and on the exhaust fan motor and belt drive. It is difficult to clean all spaces within the hood and the discharge ducts. Grease can accumulate and drip down through the seams and onto the ranges. Properly designed stainless steel ducts should be used. In all kitchen hood designs, provide openings to allow easy cleaning of discharge ducts. Fans should be kept readily accessible for frequent cleaning and maintenance by installing them inside the building, with only the fan rotor exposed to grease accumulation. Hood designs should minimize grease collection features and facilitate cleaning. Hoods on systems with intermittent fan operation should be designed so that cold air cannot enter the duct system and cause condensation on the exposed surfaces. Package kitchen hood, fan, grease extraction, and heat recovery units should be investigated from the standpoint of energy conservation savings. This type of system installation may be feasible based on the facility size and operation time. Package systems will usually require a heated enclosure (penthouse) to prevent freeze-up problems with the heat recovery and during grease wash-down cycle.

(7) *Exterior fans.* When using or specifying exterior fans, be sure they will operate in the cold ambient temperatures which will occur at the individual site. If specified fans and motors cannot operate in the ambient temperature, they should be installed on the interior of the building.

4-4. Central heating and electric power plants.

a. Central plants. Where several facilities are built together or in the same general area, consideration should be given to heating these buildings or composite camps from a central source. Utility design shall be in accordance with TM 5-852-5/AFR 88-19 Vol. 5, although the need for a central distribution system in arctic areas is stressed in this manual. Consideration should be given to installing a central system for several reasons: (1) because most facilities are remote, expert maintenance personnel may not be available at the site; (2) consolidation of facilities reduces maintenance; (3) necessary parts and supplies are in short availability; (4) there are fewer fire hazards in a central plant; and (5) maintaining supply in one fuel tank versus separate fuel tanks minimizes the number of personnel exposed to the cold weather. If a central heating plant has trouble, however, the whole base is in trouble. Therefore, redundancy of vulnerable systems can be important, but complete backup is not essential.

b. Heat recovery systems. In general, arctic facilities are in isolated locations. Since supplies are transported to most of these sites by airplane or annual supply ships, economy dictates reduced fuel consumption. As pointed out previously, additional insulation can cut fuel needs to a certain degree. Since electric power is generated at most sites by diesel generating plants, consideration should be given to the feasibility of using waste heat recovery equipment. Waste heat from diesel generators can be used for space heating, melting snow, or domestic hot water heating. Low pressure steam or hot water can be generated by waste heat recovery equipment. Engine jacket water can be used directly in building heating systems, or indirectly, through heat exchangers which heat a secondary liquid used in the building heating system. The indirect method is preferred because this: eliminates interference with engine jacket water flow; achieves better temperature control; and eliminates thermal shock to the engine. Heat recovery from the engine jacket water and exhaust gases can increase the diesel engine thermal efficiency by 30 to 60 percent. In remote areas, fuel costs (including shipment) can be extremely high, making maximum utilization of heat recovery systems important.

4-5. Humidity.

a. General. In the arctic, control of relative humidity for occupied spaces is important. The following discussion of the effects of high and low humidities illustrates the need for effective control.

b. Low humidity. Cold air contains very small amounts of moisture. For example, if outside air at -29°F and 100 percent saturation is heated to 70°F, the resultant relative humidity would be approximately 1 percent. The effects of low humidity are:

(1) *Effects on human comfort.* When the air is dry, moisture evaporates more readily from skin and makes people feel chilly even with inside temperatures of 75°F or more. Dry air removes moisture from the nasal passages and throat, causing an uncomfortably tight irritated feeling. Doctors state that relative humidity

in the 35 to 50 percent range reduces susceptibility to colds and other respiratory disorders. Hospital studies have shown that bacteria carried by personnel, including certain resistant strains, thrive in dry air with less than 35 percent relative humidity and in moist air with greater than 65 percent relative humidity. These same bacteria languish and die in the middle zone. In addition, moisture evaporation from the body causes the blood to thicken and reduces effective circulation. These problems can be eliminated by adding moisture to the air to maintain a relative humidity between 30 and 40 percent. Hospitals, computer rooms and other facilities that require or generate higher relative humidities should have moisture resistant designs.

(2) *Static electricity*. Although static electricity is being generated constantly, it does not become a problem unless it has a chance to accumulate. When relative humidity is sufficiently high, an invisible film of moisture forms on room surfaces. In the presence of normal impurities, this moisture film becomes a conductor and carries static electricity harmlessly away before it can become a hazard. With low relative humidities, however, static electricity can pose fire and explosion hazards. Control of humidity and finish materials should be designed to reduce static electricity.

(3) *Deterioration of materials and equipment.* Dryness causes brittleness and cracking of many materials including rugs, paper, and wood, which increases the combustion rate of building materials and the deterioration rate of furnishings. Dryness causes dust particles to break loose and enter the air stream.

c. High humidity. Although higher relative humidities are extremely desirable in cold climates, excessive amounts of humidity can cause serious damage. The maximum humidity to which areas should be maintained depends upon the dew point of the coldest room surface. In turn, the coldest surface depends upon the outside temperature and the type of construction. For instance, higher humidities can be maintained by using triple-glazed windows rather than double glass windows.

(1) *Condensation.* Condensation can cause structural damage when excessive humidities are maintained within the building, or within the building walls or ceilings. Condensation will occur on a cold surface whenever the temperature falls below the dew point of the air and will appear first on windows, since they will be first to reach the dew point temperature. Condensation within building walls can be effectively reduced or eliminated by a vapor retarder.

(2) *Control of relative humidity.* To maintain a reasonably controlled atmosphere, the maximum relative humidity should not exceed the amount which causes condensation. Table 2-1 shows relative humidities at which condensation will appear on different types of windows at a room temperature of 70°F. The table was developed from basic data in the ASHRAE Handbook of Fundamentals. Higher limits are possible if constant circulation forced air induction units are used underneath windows.

4-6. Plumbing.

a. General. Plumbing design, unless stated differently herein, shall be in accordance with TM 5-810-5/AFM 88-8, chapter 4, and the National Standard Plumbing Code.

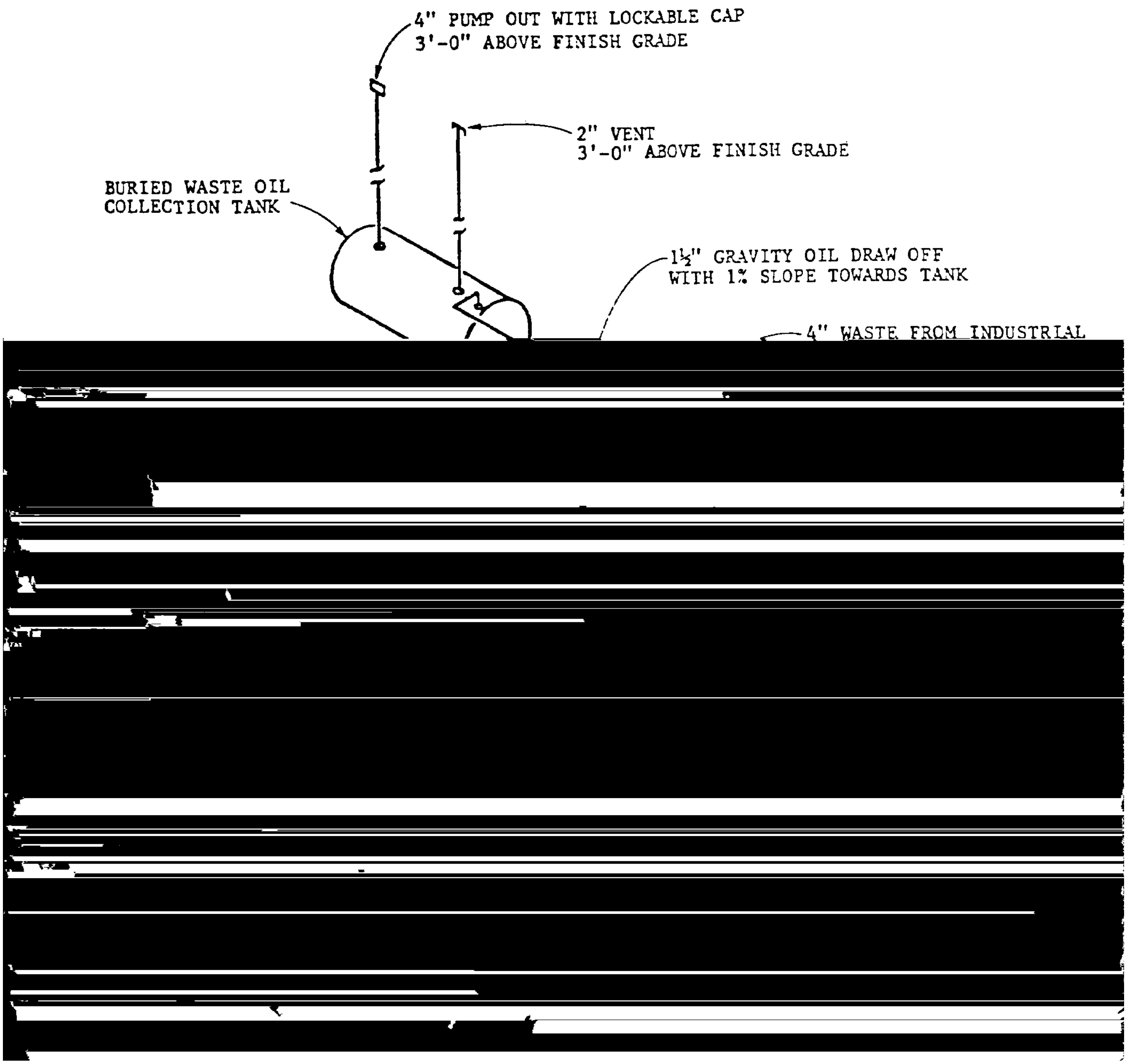
b. Special considerations for arctic areas. Where adequate water supplies are available and normal sewage systems can be installed, interior plumbing facilities vary little from those used in temperate climates. Water, however, is not always readily available in arctic areas, and sewage treatment and disposal is difficult in permafrost areas. For remote buildings and those infrequently occupied, tank type toilets with marine handpumps, floor mounted chemical toilets, incinerator type toilets, composting toilets, and recirculation type toilets should be considered. Electrical incinerating toilets installed in conjunction with gray water-black water systems have been particularly successful at some remote sites on Alaska’s North Slope. In this type of system, the black water (human waste) is separated from the gray water (laundry, shower, etc.). Each type of waste water is separately collected, conveyed, and treated. Under “combined” systems, all wastes can be piped into a sewage storage tank for ultimate conveyance to treatment and/or disposal facilities. Figure 4-4 shows an isometric piping diagram of a typical sewage system. Figure 4-5 is a typical fresh water flow diagram. Collecting small waste flows and discharging them in slugs, rather than allowing the sewage to trickle by gravity and glaciate the lines, should be considered. A water storage tank can also be installed to supply water for the domestic plumbing and fire protection systems. The water storage tank should be heated to prevent freezing. Figure 4-6 is a fire protection schematic. Figure 4-7 is a water tank heating and circulation system schematic. Water should be piped to individual buildings by the most economical method. A utilidor system may be used to distribute water along with heating and sewer lines. Utilidor design shall be in accordance with TM 5-852-5/AFR 88-19, chapter 5. An analysis of site operating capabilities, reliability of the water supply system, and fire protection requirements should be used to determine the size and type of storage tanks used for water systems. One method used to eliminate long exterior water supply lines is to drill a water well either directly in the building to be served or immediately adjacent to it.

(1) *Underfloor piping.* Buildings in permafrost areas are usually elevated above ground on a piling system. The area under the floor, therefore, is exposed to the cold arctic air and underfloor piping must be protected from freezing. This protection can be accomplished in several ways.

(a) The utility lines underneath the building can be placed in insulated enclosures and the pipes protected by heat to prevent freezing. See Figure 4-8 for a discussion on the advantages and disadvantages of heat tracing methods. Heat can be applied by four methods:

First method: Heat cables made of a nonmetallic sheath can be wrapped spirally around the pipe between it and the insulation. This technique provides uniform heating regardless of the quantity of liquid within the pipe. Pipe insulation must be removed and reinstalled to replace the heating element.

Second method: A commonly used method is installation of a mineral insulated (MI)-type, copper jacketed heat cable immersed in the liquid inside the pipe. Proper installation of the MI cable is critical to provide long service life. Improperly installed MI cables have failed after being in service 1 to 2 years, whereas properly installed cables last indefinitely. Proper installation involves the maximum use of straight pipe runs with minimum cable bending. The cable must be factory fabricated to the proper length



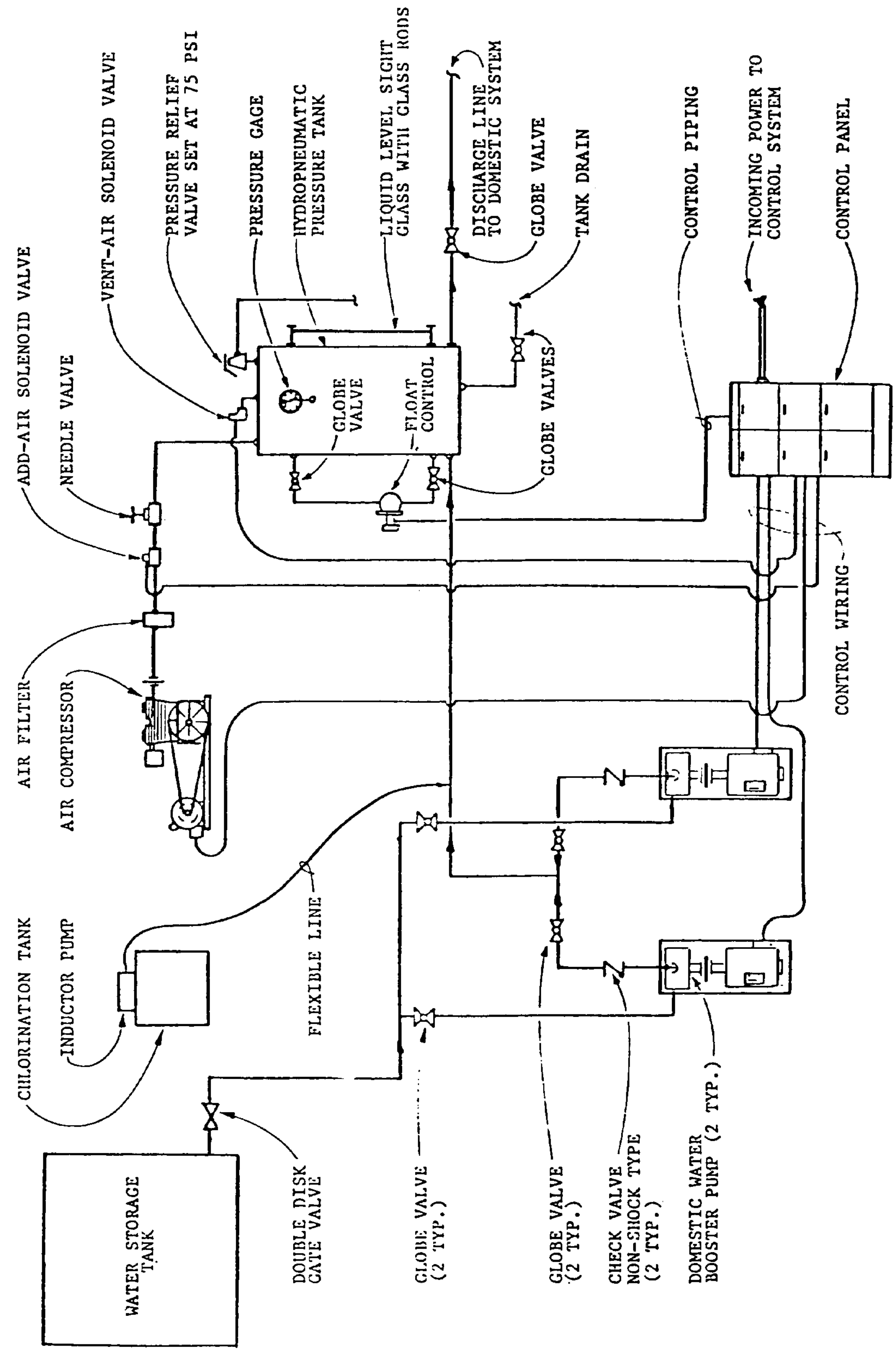


Figure 4-5. Domestic hydropneumatic water system flow diagram.

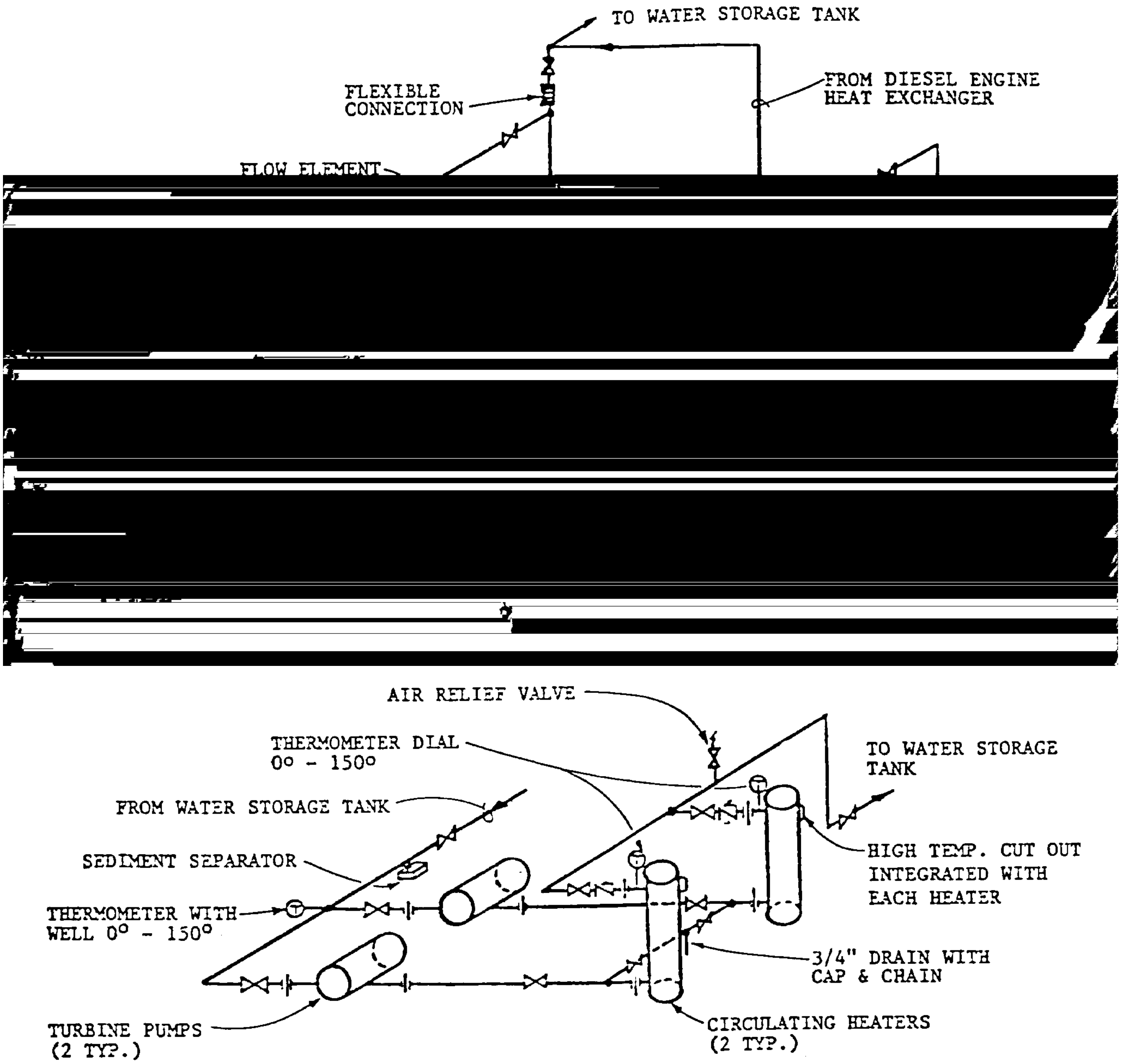


Figure 4-7. Water tank heating and circulation system schematic.

because field fabrication and assembly can easily damage the cable or its terminations. The cable is inserted into a pipe run at a tee or wye fitting with a compression gland connector. Electrical connections can be made external to the pipe in a dry junction box. Temperature is monitored with either an immersion thermostat or a thermostat bulb installed under the insulation against the pipe. This method is appropriate for water lines but should be avoided in sewage lines because of its tendency to cause clogs and blockages.

Third method: Also commonly used is installation of heat cables in small diameter conduits attached directly to, or in close proximity to, the carrier pipe and under the insulation. This method has been used successfully with both water and sewer lines. The heat cable lies loose in the conduit, allowing easy installation and removal. Steam, hot water, or a heated glycol solution may be substituted in lieu of electric heat cables.

Fourth method: The fourth method of freeze prevention is to preheat the liquid before it enters the pipeline. This method is suitable for both water and sewer lines. Circulation heaters, immersion heaters, tank type water heaters, or recirculating coil (electric or glycol solution) type heaters may be used, depending on the fluid and system type.

	ADVANTAGES	DISADVANTAGES
A. FLUIDS		
1. Heat transfer fluids	Precise temperature control.	
a. Glycols	Can retrofit a steam system to use aqueous glycol solutions. Depresses freezing point of water.	Needs a circulating system.
b. Heat process fluids (organics)	Precise temperature control. Wide temperature range. Low freezing temperatures.	Relatively expensive. Needs a circulating system.
2. Steam	Can take advantage of waste steam. Rugged. No danger of arcing in explosive environments. High heat transfer rates are possible (can provide rapid melt-out). Does not need a reliable electric power source.	Non-uniform distribution of heat. Expensive to install and maintain. Temperature control is not precise. Not always practical above 200°(400°F) due to high vapor pressures involved.
B. ELECTRICITY	Precise temperature control. Various temperature control options.	Needs a reliable electric power source.
1. Resistance	Relatively inexpensive.	Exposure to high temperatures and/or moisture will damage some insulation and cables.
a. Series	Rugged. Capable of high temperatures.	Cannot be field-cut. One break in the cable causes an open circuit. Will burn out if crossed over itself.
b. Parallel	Can be field-cut. If a resistor fails, heating circuit is still maintained.	Relatively fragile.
1) Continuous and zonal		Will burn out if crossed over itself.
2) Self-limiting	Will not burn out if crossed over itself. Responsive to local heat demands.	Somewhat more expensive than other forms of parallel heat tape.
2. Skin effect	Simple components (i.e. easy to construct and repair). Rugged. Needs relatively few energy inputs. Can be part of prefabricated insulated pipe bundle.	Impractical for applications less than 150 m (500 ft) long.
3. Impedence	High heat transfer rates are possible. Can be easily retrofitted on existing metal pipeline systems. High temperatures are possible. Heating element (pipeline) cannot burn out.	Need to insulate pipe surface in order to avoid electrical hazard to personnel. May need to electrically isolate flanges and pipeline from support structure. Requires specific design for each application.
4. Inductance	High temperatures are possible. High heat transfer rates are possible. Heating element cannot burn out.	Very expensive. Irregularities such as valves and flanges difficult to design for. Requires specific design for each application.

Figure 4-8. Advantages and disadvantages of available heat tracing methods.*

*An Introduction to Heat Tracing, by Karen Henry, Cold Regions Technical Digest No. 85-2, August 1985.

*Figure 4-8. Advantages and disadvantages of available heat tracing methods.**

*An Introduction to Heat Tracing, by Karen Henry, Cold Regions Technical Digest No. 85-2, August 1985.

(b) A special enclosed heated crawl space immediately below the ground floor elevation may be provided in arctic building design. Its floor can be constructed with removable insulated panels. All piping, including hot and cold water, heating lines, and waste piping, can be run in this space. The area must be tightly sealed to avoid air infiltration. This system has several benefits: piping is readily accessible for maintenance; it can be replaced easily; and the space provides a buffer zone to warm the floor above.

(2) *Disposal of roof and floor drainage.* Drainage from roof and floor drains should not be piped to the sewage system since this would increase sewage treatment requirements. This drainage must be disposed of separately. As discussed in (b) below, an exception is allowed. Although no perfect disposal method has been developed for all situations, several usable systems are presented below.

(a) Dry wells are underground manmade cavities below the seasonal frost level. They can be constructed by burying concrete pipes, concrete rings, or pockets of large stones or gravel capable of holding large volumes of water. Dry well use is limited to subarctic areas with free draining soil free of permafrost. If wells or connecting drains freeze, they will back up water toward the roof and create leaks within the building. Silt, leaves, and other foreign materials deposited on roofs are carried through the strainers into the roof drain system. This material seals off dry wells so that no leaching occurs after a few years. Oil can also seal off drainage in dry wells. Dry wells which become inoperative must then be replaced with new wells.

(b) Roof drain lines which discharge through an exterior wall onto a splash block cause glaciation. When this glaciation occurs on paved vehicular or aircraft traffic areas, one solution is to use a concrete trench with a grate cover to move water and glaciation away from the area. Frequently the exterior wall outlets freeze solid, backing up water in the rain leader. For this reason, an overflow line from the rain leader is connected to the sanitary sewer inside the building to allow the back up water to escape. Usually cyclic freezing occurs in the outlet during breakup conditions. Overflow drains are not included in the building waste water fixtures unit calculations.

(c) Floor or trench drains in shops collect considerable mud, gravel, sticks, and vegetation brought in by tracked and wheeled vehicles. Baskets, strainers, and sand and oil traps must be provided to keep these drains operational. Drains, traps, and underfloor piping are difficult and costly to install and maintain, but floor and trench drains are generally essential to carry away melted snow carried in by vehicles.

(3) *Roof drains.* Exterior roof drains may be damaged by snow and ice accumulation. When required, roof drains should be a minimum 4 inches in diameter to reduce probability of closure by ice and frost. Interior roof drains should be provided or roof drains should be eliminated and the roofs sloped to the eaves.

(4) *Roof vents.* In subarctic regions, vent pipes should be increased one pipe size to prevent complete frost closure. The minimum vent size should be 3 inches as required by TM 5-810-5. In true arctic areas, vents should be insulated along their full length to their termination above the roof.

(5) *Installation of plumbing vents.* In high snowfall areas, plumbing vents on gable-type metal roofs with cold attics should be installed near the roof ridge or should be reinforced to withstand snow and ice loads. Figure 4-9 shows snow accumulation on a roof of this type in a subarctic area. Snow or ice slides may break off vents and other projections.

(6) *Heating grease and oil traps.* If the water in grease and oil traps freezes, the traps will become inoperative. Heating is required to keep these traps operational. These traps may be installed inside the building to prevent freezing.

(7) *Use of lightweight material.* Lightweight materials should be considered when air transportation to the site is required. Materials to reduce installation costs, such as copper or plastic piping, should also be considered. Current guide specifications should be checked for restrictions on the use of plastic pipe which must be able to withstand extremely low temperatures. There must be adequate design considerations for plastic's higher coefficient of expansion. Pressed steel or lightweight fiberglass plumbing fixtures are available and are more suitable for transport by air than the heavier cast iron fixtures. Such materials, however, must meet minimum operational requirements.

(8) *Garbage disposals.* At small, remote installations where sewage treatment and disposal are particularly difficult, garbage disposals are generally not installed. If disposals are installed, grease removal must be considered. Grease may congeal and clog cold sewer lines, and may also create operation and maintenance problems at the sewage treatment facility. Oversized exterior grease traps have been used to remove grease, but frequent cleaning is required. The normal foodstuffs run through a garbage disposal also have a tendency to reduce the life of a septic system drain field or leach pit.

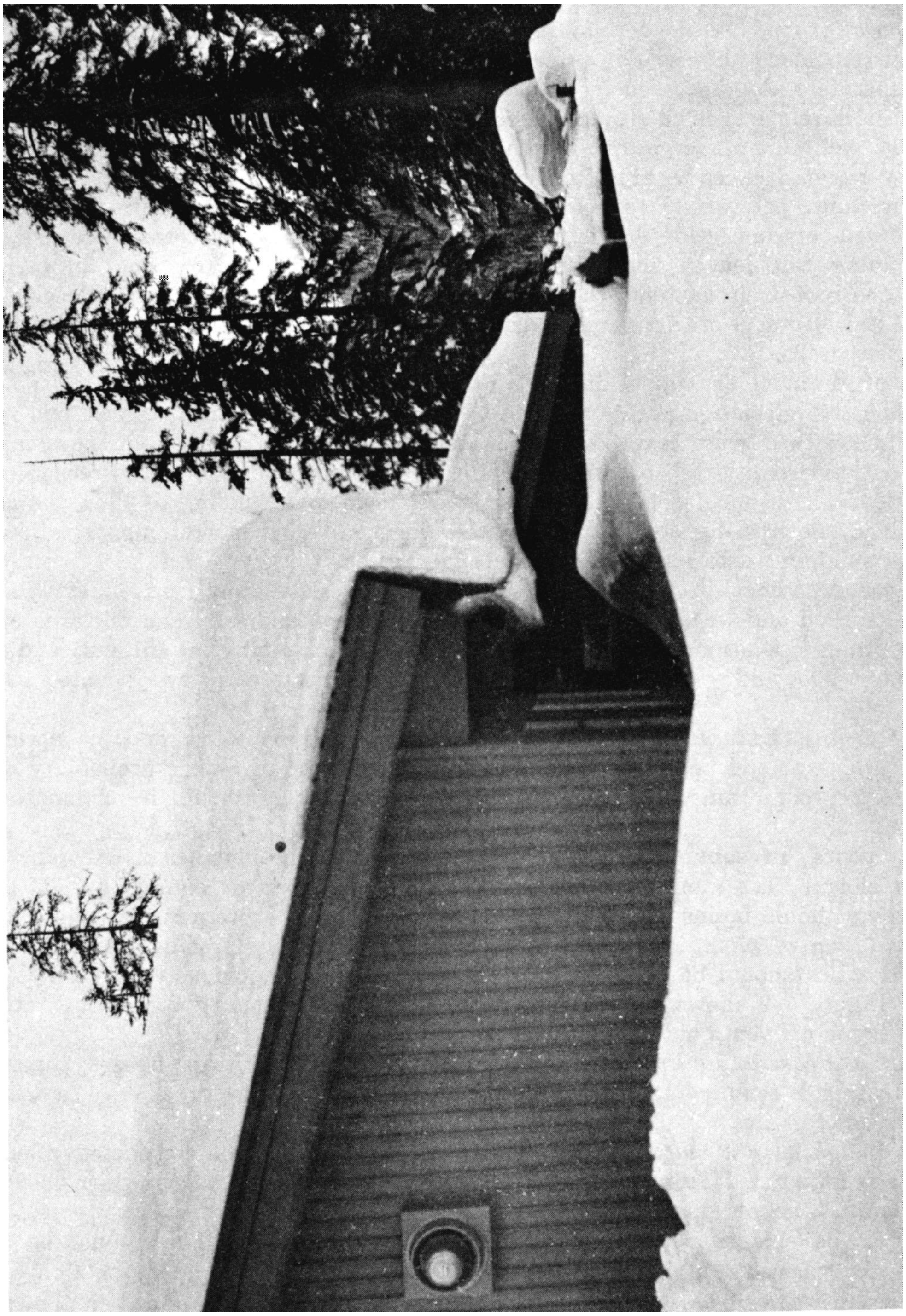


Figure 4-9. Example of snow accumulation on a roof.

(9) *Utilidor entrances to buildings.* Where high pressure steam lines enter a building through a utilidor, a utilidor cutoff (separation) wall must be provided to assure that steam leaking from the main lines does not enter the building. Cutoff walls are generally cast concrete, and the piping passes through calked wall sleeves.

4-7. Refrigeration.

a. General. Refrigeration design for cold storage should be in accordance with TM 5-810-3/AFM 88-8, chapter 2, and refrigeration design for air conditioning systems should be in accordance with TM 5-810-1, except as modified herein.

b. Special considerations. Standard refrigeration systems can be used very effectively if a few precautionary procedures are followed.

(1) *Remote air condensers.* Dissipating heat from refrigeration systems is a serious problem in arctic environments. Water condensers normally are precluded, since water is not always available and the waste water disposal is difficult. Air condensers are used but their operation is limited unless controls are provided for low ambient temperatures. The head pressures on air cooled condensers must be kept from dropping so low that the thermostatic expansion valve ceases to feed refrigerant. Crankcase heaters, pump-down control, and liquid receivers are often required for cold weather operation. Many methods can be used to control system head pressure. Some of these methods are discussed in the following paragraphs.

(a) Shutter control. Shutters which control air flow across the condenser coils will only control the system down to 20°F to 30°F. Consequently, shutters are not satisfactory for most winter operations and should not be used.

(b) Pressure type controls. Several standard methods can successfully control head pressure in a refrigeration system. One method which controls fan operation with a pressure sensor is satisfactory down to approximately 10°F. Another method utilizes a back pressure valve which bypasses and recirculates hot gas into the liquid line. This method is by far the most successful and can effectively operate down to 0°F.

(c) Enclosures with recirculating dampers. For temperatures below 0°F, a condenser enclosure must be provided so that the condenser can operate within a closed system. The temperature within the enclosure is then controlled by operation of the bypass exhaust air and fresh air dampers. Heat must be provided within the enclosure to control minimum temperatures during the off cycles. The combination of enclosure and recirculating damper has proven to be the most successful head pressure control system.

(2) *Outside air for air conditioning.* Air conditioning is frequently required in the subarctic and arctic regions to cool electronic equipment or provide climate control for scientific operations. Adequate cooling and temperature control can usually be achieved by using one of the following systems.

(a) Mixing outside air and return air. Cool outside air can be mixed with return air to obtain the desired cooling temperature or can be heated to the desired temperature with a heating coil. When temperatures exceed approximately 55°F, the system must sometimes be supplemented with mechanical refrigeration. An outside thermostat can be used to change over automatically from mechanical refrigeration to outside air cooling. One of the drawbacks to using outside air for cooling computer room equipment is that the air must be free of dust. Large air filter banks are used to filter the incoming outside air. An efficiency of 99 percent plus with a 5 micron particle size is usually required.

(b) Package air conditioning units with glycols. A package air conditioning system consists of an air conditioning unit with a mechanical refrigeration unit, an economy cycle glycol unit, and a glycol drycooler. The drycooler is located outside the structure. A single sensing control element to automatically control the temperature of both the freecooling coil and the refrigeration cycle shall be used to provide proper operation sequence. The control system will direct cool glycol solution from the drycooler to the freecooling coil as long as the glycol solution from the drycooler is providing adequate cooling capacity. The compressor operation will only switch on when the freecooling coil cannot handle the total cooling requirements. This type of system works well in arctic climates because of the cold outside temperatures. Most package systems of this type can operate up to 10 or 11 months of the year.

(3) *Cooling towers.* Water from cooling towers used in arctic climates must be drained into a sump during cold weather. The tower itself generally is not heated.

4-8. Miscellaneous. The following subtopics relate to many types of systems and are grouped here for simplification purposes.

a. Economical insulation thickness. The cost of supplying fuel to arctic sites is extremely high when it has to be airlifted. For this reason, a special economic analysis needs to be made to determine the proper insulation thickness based on a balance between reduced fuel costs and increased construction costs. The optimum U-value should be determined from a life cycle cost analysis that includes a consideration of all initial, operational, and energy costs. For buildings where heating loads will be met predominantly by space heating rather than internal gains, the following procedure is recommended to determine the most economical insulation thickness. This procedure is based on CRREL Report 82-27. Buildings with significant internal gains, the potential for using heat exchangers, or complex heating and ventilation requirements should be subject to a more sophisticated analysis than that outlined below.

(1) Calculate a climate-heating cost parameter (CHC) which will pertain to any building sharing the same site and heating costs by using the equation 4-1:

$$CHC = (24)\,(5/6)\,(HDD)\,((P/B)\,FC + (P/A)\,OMC))/FE \qquad \text{(eq 4-1)}$$

where: 24 = factor converting days to hours
5/6 = factor accounting for internal heat gain (alter appropriately)
HDD = heating degree-days (65°F base)
P/B = present worth factor* for escalating fuel costs
FC = fuel cost ($/Btu)
P/A = present worth factor for uniform series (O&M costs)
OMC = plant operation and maintenance costs
FE = combined efficiency of plant and distribution system.

**Note:* The use of present worth factors is found in National Bureau of Standards (NBS) Handbook 135 and cited in Defense Energy Program Policy Memorandum 85-2.

(2) Choose a minimum acceptable R-value (Ri) and per square foot construction cost (CCi) for each construction component (e.g., walls, roofs, exposed floors).

(3) Establish the higher R-values (Rf) and per square foot construction cost (CCf) for each alternative improvement to the minimum identified in paragraph (2).

(4) Calculate the savings-to-investment ratio (SIR) for each alternative improvement using the equation 4-2:

$$SIR = (CHC)\,\frac{(1/Ri - 1/Rf)}{(CCi - CCf)} \qquad \text{(eq 4-2)}$$

(5) Choose the option with the highest SIR.

b. Low temperature lubricants. Fans or other moving equipment mounted on a building's exterior or located within unheated portions of the building should be capable of operating at the lowest ambient temperature. The lowest operating temperatures for the piece of equipment should be stated in the specifications. Special low temperature lubricants must be used. Manufacturers should be required to guarantee their equipment under the extreme weather conditions expected at the site.

c. Air compressors and their operation. The following suggestions for air compressor system operation and design apply to both instrument air and compressed air in shops and hangars. Water vapor, if not removed, can freeze and cause the system to quit functioning. Pneumatic control systems require dry air to function properly. Exterior air should be the air source for large compressors. The cold outdoor air contains less moisture, and therefore less water must be removed from the system. For example, heated room air at 70°F and 10 percent relative humidity has .0015 pounds of moisture per pound of dry air, while outside air at -20°F and 100 percent relative humidity has .00025 pounds of moisture per pound of dry air. At these conditions, the room air has six times as much moisture as the outside air.